LESSON 9

Power of a Motor

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The motor in a small tugboat has enough power to pull a much bigger ship along slowly.

INTRODUCTION

How powerful is the motor you have been using in your investigations? In previous lessons, you examined its ability to lift loads under different operating conditions. You also measured the work performed as the motor lifted a load of washers, and you found that the motor could not lift a sled. In Lesson 9, you will learn how to calculate the motor's power output by measuring the time it takes the motor to do a specific amount of work. You will also discover how the motor's power depends on the number of batteries connected to it.

OBJECTIVES FOR THIS LESSON

Calculate the power of a motor.

Investigate how the time it takes a motor to lift a load depends on the number of batteries connected in series to the motor.

Investigate how a motor's power depends on the number of batteries connected in series to the motor.

Getting Started

1. If you have not already done so, read "Work, Energy, and Power" on page 84. Then answer the following questions in your science notebook:

A. How are work and energy related?

B. How do you calculate power?

C. What are the most commonly used units of measure for power?

2. Before you start this inquiry, you need to practice calculating power. Two situations are described here. For each, calculate the power output. Practice these calculations on your own, writing them in your science notebook. You may want to use them later to help with calculations for this lab.

A. A girl pushes at a steady pace with a force of 8.0 N on a box. She moves the box 3.0 m in 5.0 s. What is her power output?

B. A motor steadily lifts a load that weighs 5.0 N a distance of 1.5 m in 2.0 s. What is the power output of the motor?

3. What factors might affect the time it takes a motor to lift a load? Discuss your ideas with the class.

MATERIALS FOR LESSON 9

For you and your lab partner

- 1 pegboard assembly
- 3 large washers
- 1 electric motor with wire leads and alligator clips
- 1 motor pulley with nail
- 1 motor clamp
- 3 machine screws and wing nuts
- 3 D-cell batteries
- 3 D-cell battery holders
- 1 knife switch
- 5 insulated connector wires with alligator clips
- 1 large paper clip
- 1 piece of string
- 1 meterstick
- 1 0- to 2.5-N spring scale
- 1 piece of masking tape
- 1 student timer

WORK, ENERGY, AND POWER

You learned in Lesson 8 that work is done when a force acts on an object as the object moves over a distance. When work is done, energy changes from one form to another. Energy is defined as the ability to do work.

In Lesson 8, when you connected the battery to the motor, the battery's chemical energy converted to electrical energy and then to mechanical energy in the motor. The motor's shaft turned and pulled a load of washers. As the motor lifted the load, the motor's mechanical energy changed to other forms of energy. Some of the mechanical energy of the motor became kinetic energy in the moving load and heat in the motor, while some of it became gravitational energy in the load as the load was lifted.

In this lesson, you will explore the time it takes the motor to lift a load. How long a motor takes to lift a load reveals something about the motor's power. To find the motor's power, you need to know how much work the motor does each second.

Power is the rate of doing work, or the amount of work done each second.

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

The common unit of power is the watt (W), named for Scottish engineer James Watt, who improved steam engines in the late 18th century by making them safer and more efficient. One watt is equal to doing 1 newton-meter (or joule) of work in 1 second.

$$1 \text{ watt} = \frac{1 \text{ newton-meter}}{1 \text{ second}}$$

To calculate power in watts, measure work in newton-meters (N-m) and time in seconds (s), and then divide the work by the time it takes to do the work:

$$\text{Power (W)} = \frac{\text{Work (N-m)}}{\text{Time (s)}}$$

Because work changes energy, power can also be defined as a measure of the rate at which energy is supplied or used. A 60-W lightbulb uses 60 N-m (joules) of energy each second it operates. A 100-W motor can do 100 N-m (joules) of work each second.

People use other units to measure power. In situations where the watt is too small a unit, people measure power in larger units, called kilowatts (kW). One kW equals 1000 W. Both words describe both electrical power and mechanical power, like the power of your motor.

You may have heard of another unit of power—horsepower. Horsepower is often used to describe the power of car engines and motors. You will read about horsepower later in this lesson, in a reader called "How Many Horses?"

Inquiry 9.1
Measuring Power

PROCEDURE

1. Set up the pegboard assembly as shown in Figure 9.1. Include each of the following steps:

A. Make sure the string is long enough to reach from the motor to the floor.

B. Tie one end of the string to the nail on the motor shaft. Put a small piece of tape over the string where it is tied to the nail to keep the string from slipping when lifting the load.

C. Attach three washers to a paper clip at the free end of the string, so that the hanging washers just touch the floor.

2. You will measure and record the time it takes the motor to lift three washers when one battery is connected, and then when two batteries and three batteries are connected in series. Before you begin, design a data table in your science notebook with columns for three time measurements and an average time for each of the three battery arrangements.

3. Connect one battery to the motor. Close the switch. Record how many seconds it takes the motor to lift three washers to the tabletop. Lower the washers until they just touch the floor. Raise the washers again and record the time. Repeat this for a total of three measurements.

4. Record the three time measurements in your data table. Calculate and record the average time of the three trials.

5. Discuss the following questions with your partner and record the answers in your notebook:

A. What effect would adding a second battery in series have on the time it takes the motor to lift the washers?

B. Why do you think this will happen?

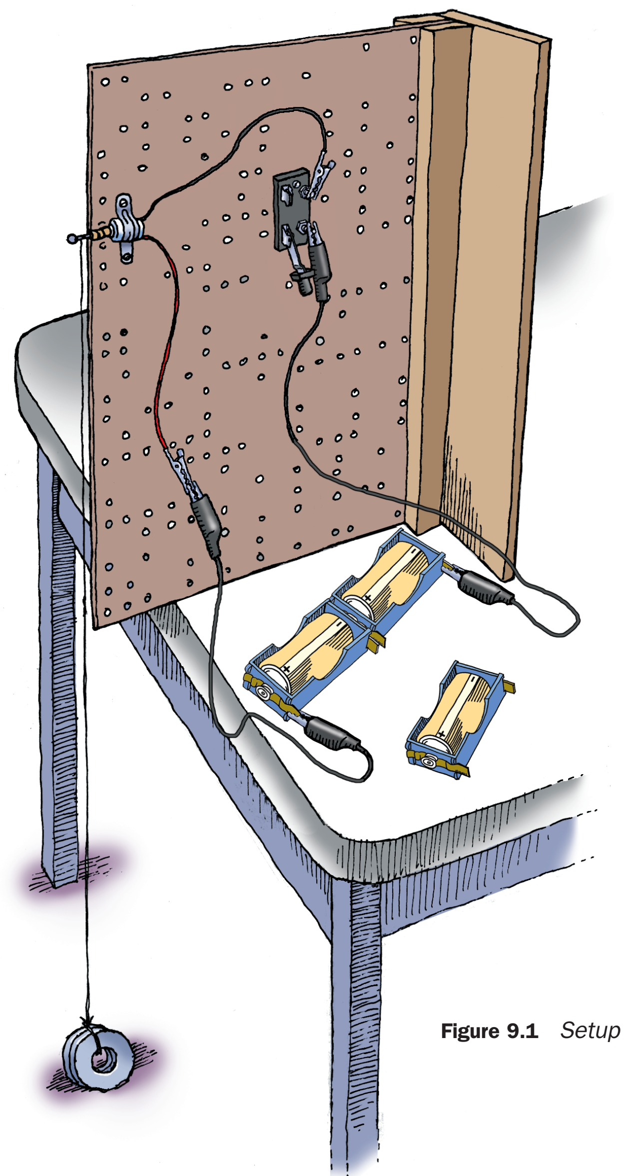

Figure 9.1 *Setup for Inquiry 9.1*

6. Now try it. Measure and record the time it takes to lift the washers to the tabletop. As before, record the time measurements in your data table and then calculate and record the average time. How well did you predict what would happen? Record your comments in your notebook.

7. Add a third battery in series to the motor. Determine the average time it takes to lift the washers in the same way.

8. Using the information recorded in your data table, graph the average time it takes to lift the washers versus the number of batteries in series.

9. Use the spring scale to measure the weight (in newtons) of the three washers. Record this information in your science notebook.

10. Measure the vertical distance (in meters) that the motor lifted the washers each time.

11. Using the weight and distance measurements, calculate and record in your science notebook how much work the motor did to lift the washers.

12. Calculate and record how much power the motor provided using one battery. Remember:

$$\text{Power (W)} = \frac{\text{Work (N-m)}}{\text{Time (s)}}$$

13. How much power did the motor provide using two batteries? Three batteries? In your science notebook, make a table with columns for "Power" and "Number of batteries." Record the power data in the table.

14. Use your table to plot a graph that represents "Power" versus "Number of batteries."

REFLECTING ON WHAT YOU'VE DONE

Answer the following questions. Support your answers with evidence from your data. Be prepared to discuss your answers with the class.

A. Did the amount of work done each time by the motor to lift the load depend on the number of batteries used in the circuit? Why or why not?

B. Suppose you made a graph of the work it takes to lift the washers versus the number of batteries. Describe what that graph would look like or draw a picture of such a graph.

C. What changed as you added more batteries?

D. Look at your graph of "Average time to lift" versus "Number of batteries." Is the time needed to lift the washers related to the number of batteries added in series? How?

E. Look at your graph of "Power" versus "Number of batteries." Does the power to lift the washers depend on the number of batteries in series? How?

F. Suppose you need to lift a larger load. What can you do to make the motor produce more power?

G. The batteries supplied energy for the motor circuit. Did the motor use all the energy supplied by the battery to lift the load? If not, what other forms does the battery's energy become?

HOW MANY HORSES?

It was the late 1800s, and engineer James Watt was stumped. He'd just figured out a way to make steam engines operate much more efficiently. He wanted to start manufacturing and selling his new invention. But how could he describe how powerful these amazing engines were?

Watt's answer? Compare the power of the steam engine with something that people were very familiar with: the power of a horse.

In Watt's day, ponies were used to pull ropes attached to platforms that lifted coal to the surface of the earth. Watt measured how much these loads weighed. Then he determined how far the ponies could raise them in one minute. Using these measurements, he calculated how much work a pony could do in a minute.

At that time, the unit of work used by British scientists was the foot-pound (ft-lb). On the basis of his observations and calculations, Watt found that a pony could do 22,000 ft-lb of work a minute. Because he figured that the average horse was as powerful as 1.5 ponies, he multiplied the power of one pony (22,000 ft-lb of work per minute) by 1.5 and called it 1 horsepower (hp).

Ponies sometimes provided the power to pull loaded carts from mines.

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The power of horses is still used to do important work.

In other words, 1 hp is 33,000 ft-lb of work per minute, or 550 ft-lb of work per second. This means that an average horse can lift a 550-lb load a distance of 1 foot in 1 second.

Horsepower can be translated into watts (W): 1 hp equals 750 W. A 350-hp engine, therefore, has the same power as a 262,500-W engine. But when numbers get as big as this, you can see that watts aren't a convenient way of expressing the power of engines. Using the word "horsepower" also probably makes drivers feel closer to the good old days—when people were pioneers and mustangs were horses! ☐

QUESTIONS

1. Why do you think James Watt used a horse as a measure of a unit of power?
2. How did Watt decide the value of 1 horsepower?
3. Why is the horsepower still a useful unit of power?

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Horsepower is still used to describe the power of motors. How much horsepower does this outboard motor provide?

The Power of Nature

NATIONAL GEOPHYSICAL DATA CENTER

Earthquake damage

Tidal waves wallop buildings. Earthquakes flatten highway overpasses. Tornadoes fling cars and trucks from one place to another. The power of nature is a hot topic on disaster shows and the evening news. But do you ever really think about how much energy is released in these disasters?

When a tornado's winds reach 320 kilometers per hour, that tornado is releasing energy at a rate of 1 trillion joules per second. Tornadoes sprout from the dark clouds of thunderstorms, which are even more powerful

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Powerful tornadoes can strike suddenly and cause great damage.

than the tornadoes they spawn. Thunderstorms large enough to generate tornadoes can release 40 trillion joules of energy per second. (That's 40, plus 12 zeroes.) Lightning is another product of thunderstorms. A single bolt of lightning produces power at the same rate that a tornado does, but the energy is in a different form and is released in a shorter period of time than a tornado's energy.

How do all these billions and trillions relate to daily life? The energy generated by one bolt of lightning could light a 100-watt bulb for three months. When a ton of dynamite explodes, it produces about 63 million joules of energy. A tornado releases more than 15,000 times that much energy every second. Hurricanes, too. The energy a hurricane releases in 24 hours is equal to all the electricity used in the United States over a period of six months.

A powerful bolt of lightning releases a tremendous amount of energy in a very short time.

Nature doesn't limit its displays of power to storms. Volcanoes can launch huge boulders 10 kilometers through the air. Earthquakes can produce as much power as a small nuclear weapon can. Earthquakes on the seafloor cause giant waves called tsunamis (a Japanese word). Tsunamis can cross oceans and become as high as a 10-story building by the time they reach land. Tsunamis this powerful can demolish entire coastal cities.

The most memorable displays of nature's power are destructive, but the power of nature isn't always violent. The

power of oceans and rivers—hydroelectric power—produces up to 13 percent of the energy consumed in the United States. Central and South America get as much as 27 percent of their energy from the power of moving water. And each day, more solar energy reaches the earth than the planet's population could use in 25 years.

So next time you hear the rumble of thunder, feel the heat of the sun on your face, or watch ocean waves crash onto the beach, take a moment to consider the power of nature. □

Volcanic eruptions are powerful enough to send ash and dust many kilometers into the atmosphere.

The power of nature can be harnessed. At Glen Canyon Dam, the power of falling water is used to generate electrical energy.